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Aschoff, J.; Daan, S.

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HUMAN TIME PERCEPTION IN TEMPORAL ISOLATION: EFFECTS OF ILLUMINATION INTENSITY

Jürgen Aschoff¹ and Serge Daan²

¹Max Planck Institut für Verhaltensphysiologie, Andechs, Germany

²Zoological Laboratory, University of Groningen, P.O. Box 14, 9750 AA
Haren, The Netherlands

ABSTRACT

Living in isolation from time cues under relatively high and low light intensities for a total (on average) of 24 days, 18 subjects estimated the passage of time by “producing” short (10 to 120 seconds) and long (1h) intervals throughout the experiments. The 1h productions were independent of light intensity and highly positively correlated with the duration of wake times. The short-interval productions were markedly increased under high light intensity. In a subsample of 6 subjects, the interaction between effects of body temperature and light condition on 10-second production was analyzed. Productions were negatively correlated with body temperature. In both dim and bright light, productions decreased by a factor of 0.7 per °C. In bright light, production was increased by a factor of 1.2 relative to dim light. This effect was not mediated by body temperature, which itself was on average slightly *increased* in bright light. Since subjective time is slowed by bright light, objective time seems to pass faster in bright light. (*Chronobiology International*, 14(6), 585–596, 1997)

INTRODUCTION

The animating effects of light have always been praised (1). Hufeland (2) ranked light, together with warmth, air, and water, among the geniuses of life: “On top is light, doubtless the closest friend and relative of life, and in this regard of a more essential impingement than generally acknowledged” (p. 43). Hufeland may have been aware of the common experience that subjective time seems to pass faster in bright light than in

Address correspondence and requests for proofs to: Prof. Dr. J. Aschoff, Jacobistrasse 29, 79104 Freiburg, Germany.

darkness, although he did not specifically mention this. As so often occurs, poets noticed the phenomenon a long time before it attracted the interest of scientists. An example is provided in the moving story *Adam Bede* by George Eliot (3, p. 372): "Thee shouldstna sit i' the dark, mother," said Adam; "that makes the time seem longer."

In the meantime, psychologists have published hundreds of articles on time perception (for reviews, see Refs. 4–8). The authors have discussed a broad variety of factors that may affect time perception, but almost none mention effects of light. In the following report, data are presented demonstrating that, indeed, the speed at which subjective time passes depends on the intensity of illumination.

METHODS

The experiments were carried out between 1964 and 1967 in two underground isolation units at Andechs (cf. Figs. 10 and 11 in Ref. 9). There, our subjects lived for weeks without any contact with the outside world and without a watch or any other information on time of day. During the subjective scheduling of their "days," subjects were asked to press a button whenever they took a meal, which they prepared. Body temperature was recorded continuously by means of a rectal probe. As a measure of the duration of sleep and wakefulness, the intervals were used between two signals given by the subjects immediately after waking and at the time they turned off their bedside reading lamp (10).

Data were collected from 18 subjects (2 females, 16 males; 22–32 years old) who lived in the unit singly for a mean duration of 24.7 ± 6.1 days. They all developed free-running circadian rhythms. In 16 subjects, the circadian system remained internally synchronized, with equal periods for the sleep-wake cycle and the rhythm of rectal temperature; the overall mean of the period was 25.0 ± 0.6 h, and the mean of the time awake was 16.7 ± 1.0 h. In two subjects, the sleep-wake cycle was lengthened to more than 28h (mean period, 35.1h), resulting in a desynchronization from the rhythm of rectal temperature, which continued to free run, with a period of about 25h (the state of "long internal desynchronization"; cf. Ref. 11).

To obtain data on time perception, 14 of the subjects had to perform two tasks: (i) they had to press a button whenever they thought that 1h had passed, with this task performed every day throughout the experiment; (ii) immediately before or after the production of the 1h intervals, subjects had to press another button for the assumed duration of 10, 20, 30, 60, or 120 seconds. Of the subjects, 8 produced two short intervals of different duration. Hence, results from 22 "short-interval" tasks were available. The 4 remaining subjects did not participate in the 1h task; they were repeatedly given signals when to produce short intervals.

In intervals of about 10 days, each subject was exposed to two different levels of illumination. For 3 subjects, the two intensities were 10 and 100 Lux; for 7 subjects, they were 40 and 400 Lux; and for 8 subjects, they were 50 and 1500 Lux. The sequence of the two light conditions was randomly distributed among subjects.

RESULTS

Circadian Parameters and Time Perception

To give an impression of the data basis, the record of a free-running rhythm is reproduced in Fig. 1. Consecutive cycles of wakefulness (open bars) and sleep (shaded

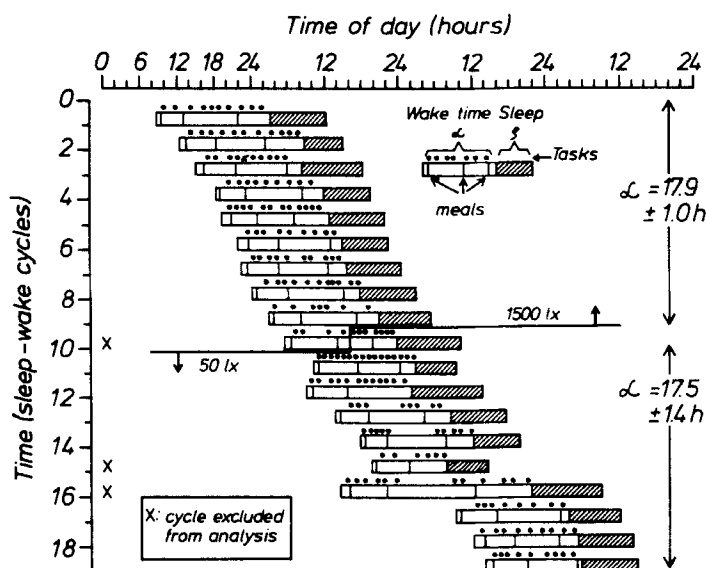


FIGURE 1. Free-running circadian rhythm of subject S.38, exposed to 1500 Lux during the first 10 cycles, thereafter to 50 Lux. Consecutive periods (open bars, wake time; shaded bars, sleep) are drawn beneath each other. Tasks for time perception indicated by dots.

bars) are drawn underneath each other. Although the rhythm in this case developed a rather long mean period of 26.7h, it remained internally synchronized, apart from one short and one extremely long (circa-bi-dian) cycle. These two cycles (15 and 16), as well as cycle 10, during which the intensity of illumination was decreased from 1500 to 50 Lux, were excluded from further analysis. It should be noted that, with the exception of cycles 12 and 15, the subject adhered to the habit of taking three meals per day in spite of the considerable variation in the duration of wakefulness (α). Hence, the intervals between meals showed a positive correlation with the duration of wake time in accordance with a general rule described earlier (12,13). The time estimation tasks (dots) were, on average, performed 10 times (range 7 to 16) per wake time.

In Fig. 2, sequences of produced time intervals from 2 subjects are plotted; for each subject, two cycles are shown that differed in intensity of illumination. Both subjects performed the 1h task and produced intervals that varied between a little less than 1h and more than 2h. For short time estimations, subject S.38 had to produce 10- and 30-second intervals, and subject S.32 had to produce 10- and 120-second intervals. As produced, these short intervals varied less than the 1h intervals and were consistently longer for S.32 than S.38. As a next step in the analysis, the long and short intervals were averaged within each cycle, and these means (computed for all cycles of the experiment separately) were then plotted as a function of the duration of wake time α . As shown in Fig. 3, the 1h intervals were positively correlated with α for both subjects and under both light intensities; from the regression lines representing the conditions, it can be seen that light had no effect on S.38, while S.32 produced somewhat larger 1h intervals in bright light than in dim light. In contrast, the short time intervals did not depend on wake time in a systematic manner, but were consistently longer in bright light compared to dim light for both subjects.

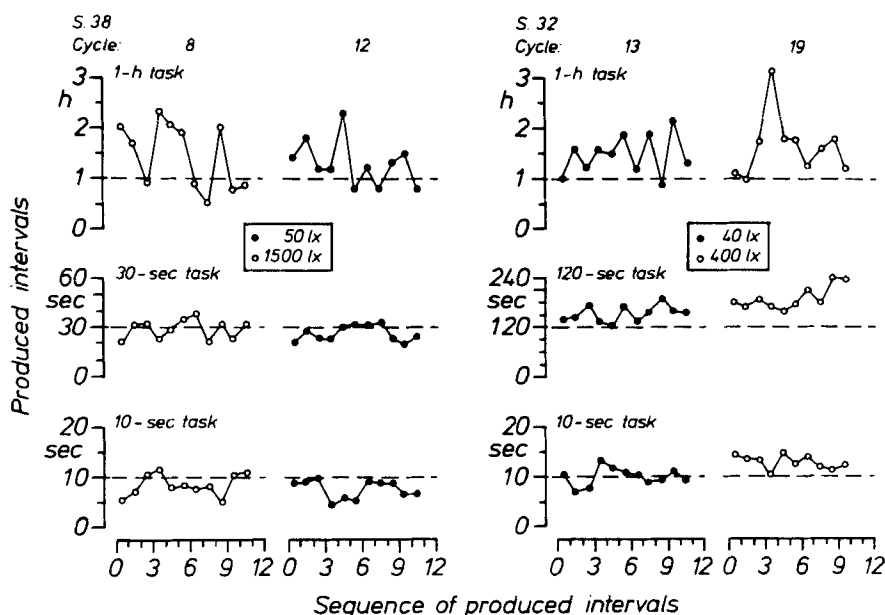


FIGURE 2. Sequences of time intervals produced by two subjects (S.38 and S.32) during one cycle in dim light (solid symbols) and one cycle in bright light (open symbols).

A summary of the results obtained with the 8 subjects exposed to 50 and 1500 Lux and the 7 subjects exposed to 40 and 400 Lux is given in Fig. 4. The two diagrams show the overall means of intervals produced in the two conditions (solid symbols, dim light; open symbols, bright light) and the regression for the dependence on α for groups of subjects who participated in the various tasks. The following conclusions can be drawn: First, the 1h intervals are positively correlated with, and vary more or less proportionally to, α (dashed lines indicate proportionality); neither the means nor the regression lines differ significantly between the two intensities of illumination. Second, the short intervals do not show a systematic dependence on α , but in all short-interval tasks the produced intervals are larger in bright than in dim light.

As a next step in the analysis, the overall means for each subject and task were calculated for all measurements made under the two conditions of illumination and expressed relative to the task interval. The same procedure was followed for τ (circadian cycle length from wake-up until wake-up) and α . According to Fig. 5, neither circadian period (τ , left) nor wake time (α , right) depends in a systematic manner on light intensity. This holds for the 16 subjects whose rhythms remained internally synchronized, as well as for the 2 subjects who developed long internal desynchronization. Similarly, the production of 1h intervals (Fig. 6, left) either increased or decreased slightly with an increase in light intensity, without any consistent trend. In sharp contrast, the short intervals produced were, without exception, longer in bright than in dim light (Fig. 6, right).

The data summarized in Fig. 5 support earlier findings that changes in light intensity (at levels below about 1500 Lux) have almost no effect on period and wake time (cf. Chapter 2.4 in Ref. 9). In view of the fact that the 1h intervals are strongly positively correlated with wake time (cf. Fig. 4), the independence of light intensity (Fig. 6, left)

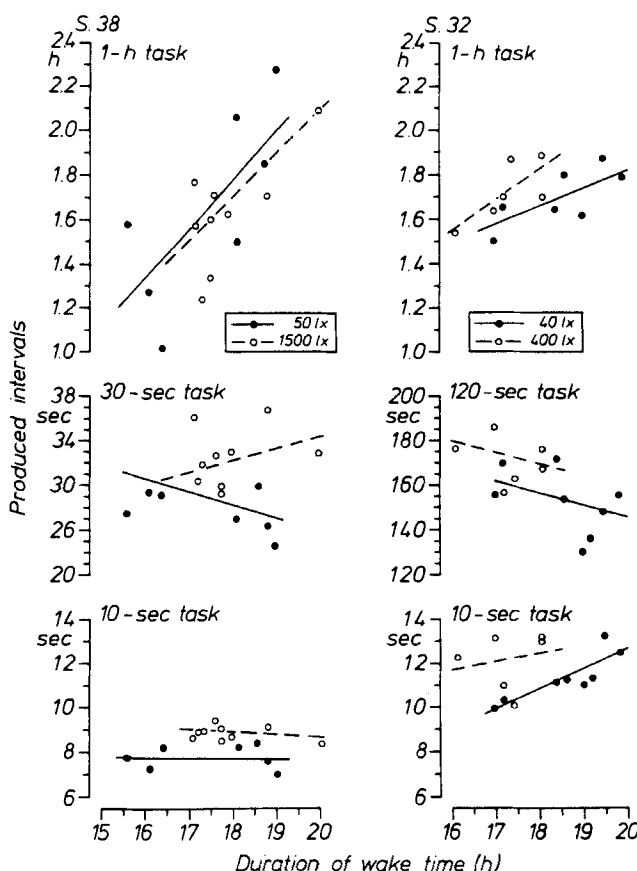


FIGURE 3. Means of time intervals per wake time plotted as a function of the duration of wake time (solid symbols and solid regression lines, dim illumination; open symbols and dashed regression lines, bright illumination) (data from the same subjects as used for Fig. 2).

is not too surprising. The short time intervals are not at all correlated with the duration of wake time (12). They seem to belong to another class of time perception that is strongly affected by the intensity of illumination (Fig. 6, right).

Effects of Body Temperature

It is well known that the perception of short time intervals depends on body temperature (8,14–17). Hence, the possibility cannot be excluded a priori that the effects of light described in the right-hand diagram of Fig. 6 are due to an increase in body temperature in brighter illumination. To test this hypothesis, data on rectal temperature as recorded at the times of the tasks from the protocols of 6 of the subjects could be used. For subject S.40, sequences of such measurements during two cycles with dim illumination and two cycles with bright illumination are plotted at the bottom of Fig. 7. These curves differ from the “normal” curve of rectal temperature insofar as the maxima occur already at the middle of wake time (instead of in late afternoon), and the evening drop

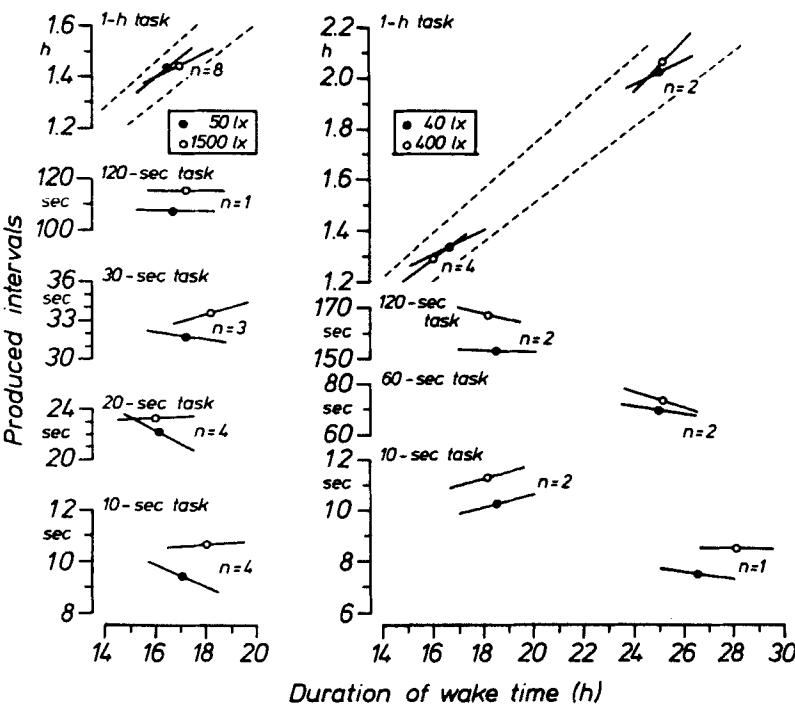


FIGURE 4. Overall means of intervals produced by n subjects in two different light intensities and plotted, together with the mean regression lines, as a function of the means of wake time. The dashed lines on top indicate proportionality between the 1h intervals and wake time.

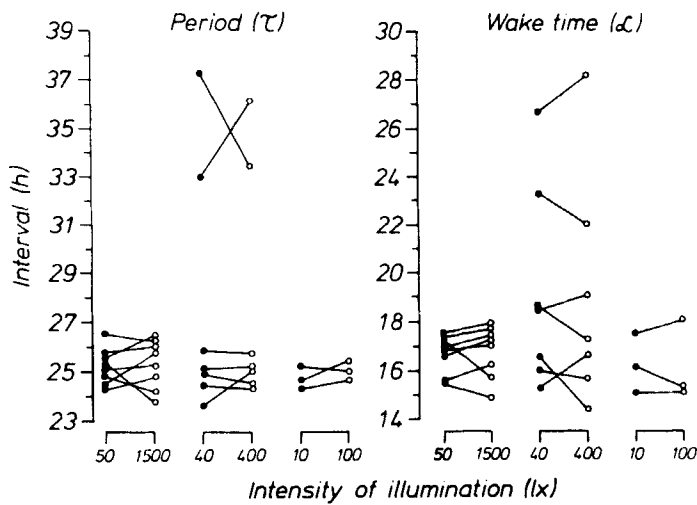


FIGURE 5. Means of circadian period (τ , left) and of wake time (α , right) recorded for 18 subjects at different intensities of illumination. Data from the same subject connected by a solid line.

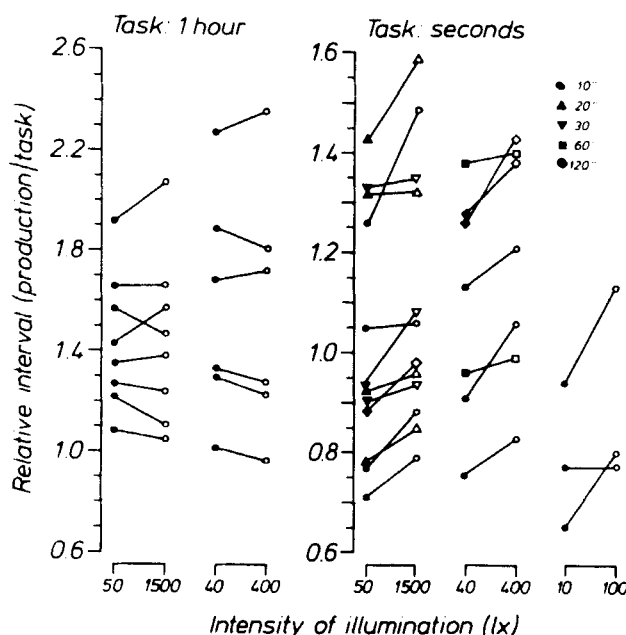


FIGURE 6. Means of 1h intervals (left) and of short time intervals (right) produced at different levels of illumination. Data from the same subject connected by a solid line.

precedes the onset of sleep by several hours, indicating a phase advance characteristic of human free-running circadian rhythms (18). Above the rectal temperature, the intervals produced in the 10-second task and in the 30-second task are plotted. In Fig. 8, these intervals are plotted as a function of rectal temperature; they show a negative correlation for all eight data sets.

The overall means of short intervals and the correlations with rectal temperature as derived from the protocols of 3 subjects who produced two different short intervals are presented in Fig. 9. For both tasks, the coefficients of correlation are mainly negative (with three exceptions for S.36), and, more importantly, the means are larger in bright than in dim light in all data sets.

As a last step in the analysis, each average daily 10-second interval produced by all 6 subjects was converted into relative units by dividing it by the individual mean of the intervals produced in the dim light condition. Also, the corresponding rectal temperatures were expressed as deviation from the individual mean values recorded in dim light. The log-transformed data—one for each cycle—are plotted against relative rectal temperature in Fig. 10 for dim light (solid symbols), together with the mean relative values for the bright light condition (open circles). The overall mean of all relative values in bright light condition is indicated by an open diamond together with error bars. This plot reveals in the first place that the 10-second intervals and rectal temperature are indeed negatively correlated in this data set, as expected on the basis of other studies (8). Second, the temperatures recorded in bright light are somewhat (on average, about 0.05°C) higher in bright than in dim light. Third, the 10-second productions are longer in bright than in dim light, opposite to the expectation based on temperature. Multiple regression analysis

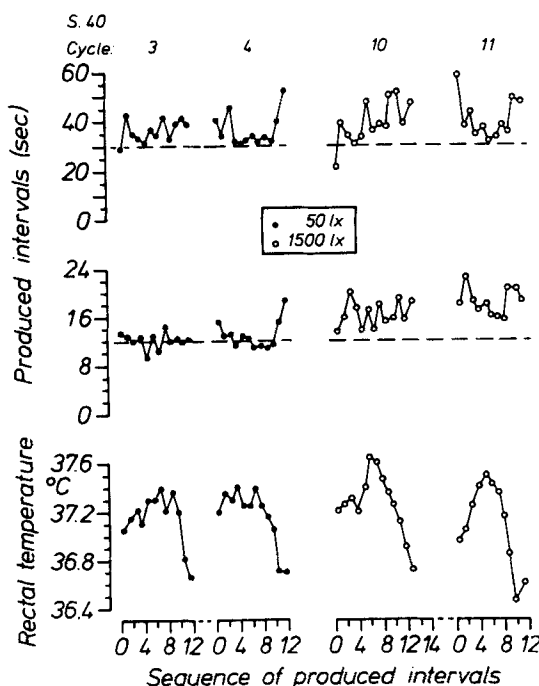


FIGURE 7. Sequences of short time intervals (upper two rows) and of rectal temperature recorded at the time of the tasks (lowest row) of subject S.40 during two cycles in dim and two cycles in bright illumination.

showed that both relative temperature (coefficient $-0.185 \log \text{ units} \cdot ^\circ\text{C}^{-1}$; $df = 81$; $t = -2.93$; $p < 0.005$) and light condition (coefficient $0.072 \log \text{ units}$; $df = 1$; $t = 4.56$; $p < 0.0001$) contributed significantly to the explained variance in \log (relative production). Introduction of subjects as dummy variables in the regression analysis did not significantly increase the explained variance. Hence, the relationship is not due to differences among subjects. The interaction term also was not significant. Therefore, we conclude that the dependence of 10-second production on body temperature (i.e., the slope of the two regression lines in Fig. 10) was not different between bright and dim light. The subjective time experience is accelerated such that 10-second production decreases by a factor of about $10^{-0.185} = 0.70$ per $^\circ\text{C}$ body temperature increase. Bright light conditions caused, on average, a deceleration by $10^{0.072}$ or 18%.

DISCUSSION

The results summarized in Figs. 4 and 6 demonstrate a fundamental difference between the perception of long time intervals such as 1h and of short intervals in the range from 10 to 120 seconds. The production of 1h intervals was proportional to the duration of wake time and was independent of the intensity of illumination. The opposite holds for the short intervals: they were not related to the duration of wake time, but positively correlated with light intensity. As shown in Fig. 10, this dependence of short

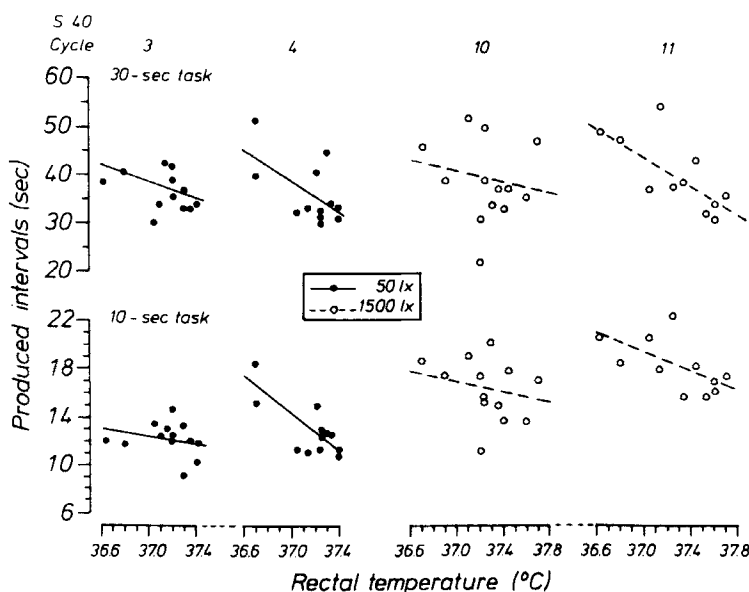


FIGURE 8. Correlation between short time intervals and rectal temperature as recorded for subject S.40 during two cycles with dim light (solid symbols and regression lines) and two cycles with bright light (open symbols, dashed regression lines).

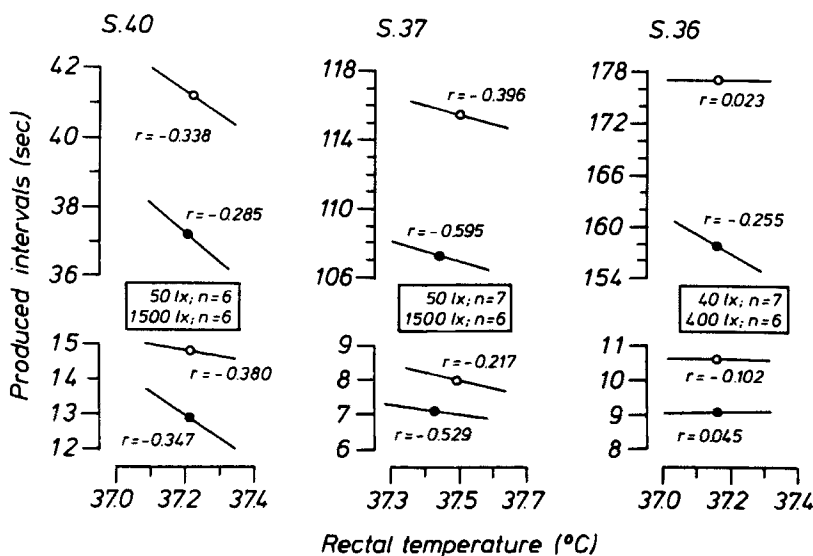


FIGURE 9. Correlation among short time intervals, produced by 3 subjects at two different intensities of illumination, and rectal temperature (closed and open circles, the overall means for each subject; solid lines, regressions).

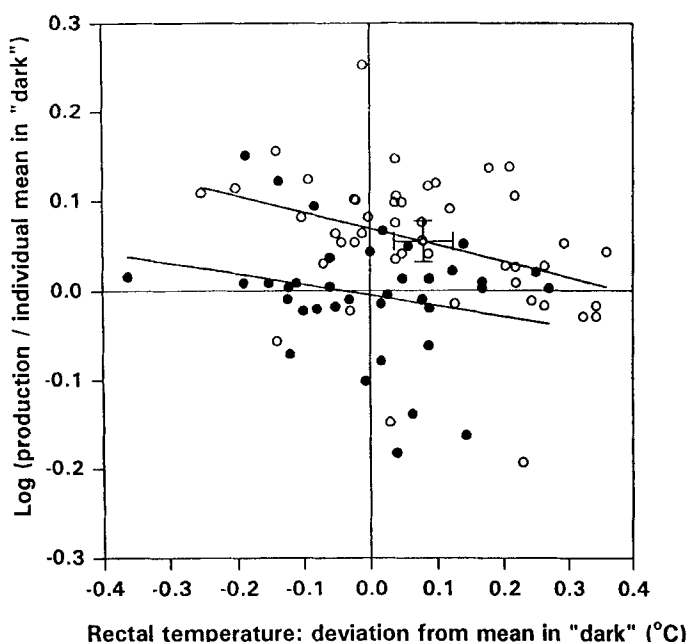


FIGURE 10. The association between relative short-interval (10-second) production and relative rectal temperature. Each symbol indicates the log transform of the mean daily interval divided by the mean of all intervals produced by the subject in the dim light condition and the temperature at that moment minus the mean temperature of the subject during all tasks in the dim light condition. Solid symbols, values obtained in dim light; open symbols, values obtained in bright light; diamond with error bars, mean of all log (mean relative production) and of all mean temperature values in the bright light condition \pm SEM. Solid lines, regression of log (relative production) on relative temperature in the two conditions.

intervals on light intensity can not be explained by effects of body temperature: in dim light, as well as in bright light, the intervals become shorter with increasing temperature, but the regression line describing this relationship in bright light is far above the one valid for dim light. In brighter light, rectal temperatures were, on average, slightly higher than in dim light (Fig. 10), in contrast to observations made by Tokura et al. (19).

We are aware of only a single report in which effects of light on the perception of short time intervals has been described (20). These authors studied 6 subjects, who were living in groups of two (in the same isolation unit as in our report), first for several days under an artificial light-dark cycle with ordinary room light, and thereafter for four days in continuous darkness. They lived on a rigorous schedule, with sleep from 23:30 to 07:30. In the first part of the experiment, lights were on from 07:30 to 23:30; in the second part, there was no light for 96h. The circadian rhythms of all subjects remained entrained to 24h. (For further details, see Ref. 21). Every third hour, the subjects were alerted by signals when they had to produce a 10-second interval. Under both conditions, the 10-second intervals showed a large 24h variation, with peak values during sleep time (subjects were awakened for the tasks) (cf. Fig. 5 in Ref. 20). The means of intervals that were produced during the wake time were 10.61 ± 0.21 seconds in light, and 9.70 ± 0.30

seconds in darkness; the difference is highly significant ($p < 0.001$) and is in the same order as the results reported here.

In extrapolating these highly consistent experimental results to everyday life, one has to keep in mind that they refer to the *production* of short time intervals: the biological "clock" used for the task runs faster with increasing body temperature, but is slowed down in bright light. From this observation, it follows that events of equal duration are *perceived* as lasting shorter in bright than in dim light. It is for this reason that, as George Eliot noticed, the passing of subjective time seems to be slowed in darkness.

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